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Cardiac output during CPR: a comparison of two methods

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ABSTRACT

Simultaneous Fick and saline dilution methods were compared for measuring cardiac output during experimental cardiac arrest and resuscitation in anesthetized dogs. During cardiopulmonary resuscitation (CPR) cardiac output averaged 53 ± 30 ml/min-kg (42% of pre-arrest values). Values obtained using the Fick vs. saline methods were highly correlated ($r = 0.96$), and were not statistically different ($t = 1.47$, $df = 16$).

INTRODUCTION

Optimization of resuscitation techniques requires accurate measurement of blood flow under the conditions of CPR. Because of the fundamental relationship: pressure = flow × resistance, blood pressure alone does not necessarily indicate perfusion in the presence of the changing peripheral resistance during CPR. Therefore, the important parameter to measure is blood flow. This report compares the direct Fick method and a modified saline indicator dilution method for measuring cardiac output during the low flow conditions of CPR with ventricular fibrillation.

METHODS

Five mongrel dogs, weighing 9-20 kg, were anesthetized with pentobarbital sodium, 30 mg/kg iv, and intubated with a cuffed endotracheal tube to provide a patent airway. Each animal was secured in the supine position to a V-shaped support board which was attached to the baseplate of a mechanical resuscitator (Thumper®, Michigan Instruments, Grand Rapids, MI). Pin electrodes were inserted to record ECG. Wire mesh electrodes were placed both under the shaved dorsum of the dog and on the 6 x 10 cm chest compression pad of the Thumper to permit dorsal-ventral defibrillation without cessation of chest compression. Catheters were inserted into the brachial artery and left jugular vein to measure arterial and venous pressures, respectively. A catheter was placed in the left femoral vein to administer fluids or drugs. Heparin (1 mg/kg iv) was given to prevent blood clotting in the catheters.

Fick cardiac output measurements

In order to measure oxygen uptake with a spirometer during CPR and fibrillation, the phrenic nerves were stimulated bilaterally with bipolar electrodes to obtain negative pressure ventilation. The electrode locations that produced vigorous diaphragmatic contraction were identified by trials of stimulation. Atropine, 0.5 mg/kg iv, was given to block effects of concomitant vagal stimulation due to current spread. The control unit of the Thumper provided a signal that allowed stimulation of both phrenic nerves between chest compressions after every 5th chest compression. Ten volt, 40 Hz, 2 msec square wave stimulation provided strong diaphragmatic contraction and vigorous negative pressure ventilation of the lungs required to obtain oxygen uptake with a spirometer.

Oxygen uptake was measured using a 5 L spirometer with a CO_2-absorber. The spirometer was calibrated with a 500 ml syringe. Oxygen uptake was measured by taking the slope of the spirometer record during CPR. The spirograms were recorded along with the dilution curves on a Physiograph chart recorder (Narco Bio-Systems, Houston, TX).

A catheter was placed in the carotid artery to sample arterial blood for the measurement of arterial oxygen content. A pigtail catheter was advanced through the right jugular vein into the right ventricle to sample mixed venous blood for the measurement of venous oxygen content. Oxygen content was measured with the Lex-O_2-Con (Lexington Instruments, Waltham, MA). Cardiac output was calculated from the Fick equation as oxygen uptake divided by arteriovenous oxygen content difference.

Indicator dilution method

Details of the saline indicator method have been reported previously [1, 2]. A pigtail catheter, advanced via the left femoral artery into the left ventricle, was used to inject forcibly 1 ml of 5% saline. A withdrawal catheter was inserted into the right femoral artery to sample downstream indicator concentration in arterial blood. Blood was withdrawn at 10 ml/min into an electrically calibrated, flow-through conductivity cell. This sampling rate was at most 6% of the measured cardiac output during CPR with ventricular fibrillation. The conductivity cell was connected to an impedance recorder (Narco Biosystems, Houston, TX) operating at 50 kHz which provided an indicator dilution curve (conductivity change vs. time) that could be calibrated in terms of saline concentration. Cardiac output was calculated from the Stewart-Hamilton formula as amount of indicator injected divided by curve area.

Experimental procedure

Two-min episodes of ventricular fibrillation and CPR, followed by defibrillation and recovery, were studied in each animal. Pre-fibrillation control cardiac outputs were obtained. Before CPR, the dog was ventilated with positive inspiratory pressure (15-20 cm H_2O) using the Thumper's ventilation circuit which was driven with 100% oxygen. Just before CPR, the tracheal tube was switched to the O_2 filled spirometer and negative pressure ventilation was initiated by phrenic nerve stimulation.

Ventricular fibrillation was produced by 60 Hz electrical stimulation of the left ventricle. A fine, stainless steel wire contained within the pigtail catheter carried current to the left ventricle for this purpose. A drop in arterial blood pressure toward zero and the appearance of fibrillation waves in the electrocardiogram confirmed ventricular fibrillation. A specially modified Thumper provided chest compressions of 30-50 lb force at 60/min with 50% compression duration. Ventilation was interposed after every 5th chest compression by phrenic nerve stimulation. The Fick and indicator dilution techniques of measuring cardiac output were performed simultaneously during a 60-sec period of ventricular fibrillation and CPR. Then the ventricles were defibrillated. If necessary, epinephrine, sodium bicarbonate, and calcium were given to promote recovery of the circulation. After each episode of CPR, adequate time was allowed for arterial blood pressure to return to a stable level.

Cardiac output values for the simultaneous Fick and saline dilution methods were compared, and the Student's t test for paired data was performed to test the null hypothesis that the values from the two techniques were the same.

RESULTS

Correlation of Fick cardiac output data with simultaneous values using the saline dilution technique was excellent ($r = 0.96$). There is no significant difference between the Fick and saline dilution methods of measuring cardiac output during fibrillation and CPR ($t = 1.47$, $df = 16$). During 17 CPR studies in the 5 animals, CaO_2 averaged 21.9 ± 1.9 ml/dl and CvO_2 averaged 8.4 ± 2.4 ml/ dl. Oxygen uptake averaged 7.0 ± 3.8 ml/min-kg compared to the pre-fibrillation value of 10.0 ± 2.5 ml/min- kg. Cardiac output averaged 53 ± 30 ml/min-kg (42% of pre-fibrillation values).

DISCUSSION

Bilateral phrenic nerve stimulation provides ventilation needed to use the Fick Method during cardiac arrest. With this technique, the authors have applied the direct Fick method for measuring cardiac output to the low flow conditions of CPR. Comparison of the saline dilution technique for measuring cardiac output [1, 2] to the Fick method failed to show significant differences, suggesting that both methods are comparable.

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